Description

POWER TAKE-OFF CONTROL SYSTEM

5 ### Technical Field

The present invention relates to a power take-off (PTO) control system and method for more optimally engaging and operating loads applied to the PTO shaft, especially for an agricultural vehicle such as a

10 tractor. In particular, the present invention relates to a control system and method for detecting variable load types and controlling the operation of a PTO clutch to effect engagement of the clutch with variable loads, and especially to more optimally effect the engagement

15 of a clutch under extreme conditions, such as a very light load, a very heavy load, and/or overrun clutches.

Background Art

PTOs are used on many types of vehicles,

20 including on agricultural vehicles such as tractors, to provide power for equipment or implements, such as, for agricultural purposes, combines, mowers, balers, forage harvesters and spreaders.

Modern tractors commonly have horsepower

25 ratings in excess of 100 horsepower. However, the shaft sizes for PTOs have not changed due to the need to maintain compatibility with older equipment and maintain the standardization for PTOs. Thus, the torque output of PTOs for many modern tractors is no longer limited by

30 the tractor horsepower. Rather, the torque output is limited by the strength of the PTO shaft and the failure thereof. In addition to causing PTO shaft failures, the torque produced by the high horsepower tractors can accelerate equipment attached to the respective PTO at a

35 rate which can damage the equipment.

In view of the problems associated with the control of PTO shafts in high horsepower tractors, it was found desirable to provide a PTO clutch control system for protecting PTO shafts from catastrophic
5   failure and for providing PTO shaft accelerations at rates which protect the shafts and attached equipment during clutch engagement.

Typical of such a system is the system of U.S. Patent No. 5,494,142, which discloses a PTO control
10 system for vehicles, such as farm tractors including a power take-off (PTO) shaft, for supplying rotational motion to an implement of the type which may be stationary or towed by the tractor. Power is transferred to the PTO shaft by a clutch including an
15 input shaft coupled to a power source and an output shaft coupled to the PTO shaft. The clutch transmits a maximum torque between the input and output shafts in response to a maximum clutch pressure and transmits a variable torque between the input and output shafts in
20 response to a given clutch engagement pressure that is less than the maximum clutch engagement pressure. Typically, a generally linear, gentle ramping up of current/pressure is employed to achieve smooth engagement.

25 The control system includes a first transducer disposed to generate an input signal representative of the rotational speed of the input shaft, a second transducer disposed to generate an output signal representative of the rotational speed of the output
30 shaft, and a control circuit. The control circuit is coupled to the clutch control, the first transducer, and the second transducer.

While such a control system has been of great value and effectiveness, it and other control systems
35 have continued to experience difficulties when attempts

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are made to drive PTO under extreme conditions. With
such systems, no differentiation was made with respect
to the loads applied, be they very light or very heavy.
With a light applied load, initial PTO shaft movement
5   could occur at a relatively early time and the full
shaft speed would be reached before a modulation is
effectively executed. With a heavy load, however,
initial PTO shaft movement would not occur until a later
time, leaving very little time for modulation.
10   The strategy of employing a generally linear,
gentle ramping up of current/pressure to achieve smooth
engagement, while effective and beneficial in many
instances, has nevertheless been found to be not as
effective as would be desirable in effecting initial
15   movement of extreme loads and smooth engagement. In
various instances, the difficulty in initiating movement
could result in either abandonment by the system of the
engagement or by a sudden and abrupt engagement, which,
in severe cases, could lead to breakage of the shaft or
20   unsafe operation.

Summary Of The Invention
          The present invention is intended to address
such difficulties as might arise when the PTO shaft can
25   be loaded with variable loads. The invention is thus
directed to a control system and method for more
optimally effecting engagement and operation of variable
implement loads that may be applied to a PTO shaft.
          By applying high amplitude/short duration
30   current shocks, such as on top of the generally linear
control curve, at different times, PTO shaft movement
can be caused to occur at earlier times for heavier
loads than has previously been the case. The high
amplitude of the current, and the consequent high
35   pressure applied through the clutch, and then the

consequent shock effect, is effective in breaking loose
static loads, such as frictions, drags, etc., and
achieving earlier movement of the PTO shaft. For safety
reasons, the PTO shaft is expected to start movement and
5   then reach full speed within a time limit, such as 6
seconds. This earlier start of PTO shaft movement will
gain valuable time for modulating shaft accelerations.
Now that the shocks will greatly help break loose heavy
static loads, the generally linear control curve can be
10   made even more gentle/flat without being concerned that
it takes too long to engage heavy load applications.
The combination of flatter linear control and longer
modulation of acceleration is beneficial in achieving
smoother PTO engagement for any load conditions.
15   The short duration of the applied shocks
ensures that the overall energy level remains low,
however, which not only protects the PTO shaft but also
ensures that the acceleration of the PTO shaft will be
determined primarily by the generally linear control
20   curve and not by the current shock. By employing this
technique, heavier static loads can be more readily
broken loose, yet smooth PTO shaft acceleration can be
achieved.
During system operation, current shocks are
25   thus applied at strategic times prior to movement of the
PTO shaft. The number of shocks required to initiate
PTO shaft movement and/or the length of time from
application of pressure until PTO shaft movement first
occurs are indicative of the applied load, with heavier
30   loads requiring more shocks and/or a longer time before
movement of the PTO shaft commences. Once movement of
the PTO shaft has occurred, the current can thereafter
be increased in known manners, including at
predetermined or newly calculated ramp rates, until the
35   maximum allowable current is reached. The ramp rate

after detection of PTO shaft movement can also be adjusted according to the determined load type and the detected and desired acceleration of the PTO shaft.

The number and timing of the current shocks

5 may be determined based upon load feedback information. In a more basic system utilizing the present invention, current is initially applied at a time t_0 and, typically, a slow ramping of the current commences. PTO shaft speed is monitored and, if movement of the PTO shaft is

10 detected prior to a time t_1, the load is considered to be a light load, and an appropriate current/pressure control curve for light load can preferably thereafter be employed during the modulation period of operation.

If, at time t_1, the PTO shaft has not commenced

15 movement, however, a light current shock is applied, or application of a series of light current shocks is commenced, at time t_{s1}, which may be essentially the same as t_1, or delayed somewhat, if so desired. PTO shaft speed continues to be monitored and, if movement of the

20 PTO shaft is then detected prior to a time t_2, the load is considered to be a medium load, and an appropriate current/pressure control curve for medium load can preferably thereafter be employed during the modulation period of operation.

25 If, at time t_2, the PTO shaft has still not commenced movement, a heavier current shock is applied, or application of a series of heavier current shocks is commenced, at time t_{s2}, which may be essentially the same as t_2, or delayed somewhat if so desired. PTO shaft

30 speed continues to be monitored and, if movement of the PTO shaft is detected prior to a time t_3, the load is considered to be a heavy load, and an appropriate current/pressure control curve for a heavy load can preferably thereafter be employed during the modulation

35 period of operation.

Still heavier shocks can be made at still later times and additional load type designations made, as may be desired. A maximum time can also be established for detecting movement of the PTO shaft,
5   with non-movement by such time being considered indicative of an overload condition. In such event, the control system can then effect a termination of the engagement operation so as to avoid damage to the PTO shaft or the vehicle engine.
10   The times at which current shocks are applied need not strictly be predetermined time periods, but may be times which are wholly or partially determined by or dependent upon system operation and associated events. It has been found, for example, that, especially with
15   heavier loads, a drop in the speed of the engine (and/or the input shaft to the PTO clutch) may be detected prior to any detected movement of the PTO shaft. Such an occurrence is indicative of a situation in which the engine is being loaded by the implement on the PTO
20   shaft, but the implement load has not yet broken loose. Often, if a current shock can be applied at this time, the load can be broken loose before the engine speed drops precipitously. Consequently, with certain embodiments it may desirable to utilize detection of
25   engine droop, or some amount of droop, and to generate a current shock if movement of the PTO shaft has not detected when the droop occurs.

The invention can also be employed in conjunction with other techniques and methods for
30   controlling engagement of a loaded PTO shaft, including techniques and methods such as are disclosed, for example, in U.S. Patents Nos. 5,494,142 and 6,267,189 and in other pending or contemplated applications of the assignee of the present application or related
35   companies, which techniques and methods, among other

things, may permit or allow automatic calibration of the
starting point based upon both PTO and engine shaft
speed, wherein the commencement of either PTO shaft
movement or engine droop, whichever is detected first,
5   will result in determination of the current being
applied at such time, which current value can be
averaged with the current values for a plurality of
previous engagements to determine a reference current
value to be used as a standing point for the next
10   engagement operation. The use of such other techniques
and methods are not necessary for the use and enjoyment
of the present invention, but systems that employ
combinations of these techniques and methods are
generally more preferable than more basic systems since
15   additional advantages and improved performance can be
realized than with the more basic systems.

Brief Description Of The Drawings

         FIG. 1 is a schematic block diagram of a PTO
20   drive and control system;

         FIG. 2 is a schematic block diagram
representative of the circuit configuration for a
controller of the control system;

         FIGS. 3A and 3B are flowcharts representative
25   of the general sequence of operation of a control system
embodiment;

         FIG. 4 is a graphical representation of a
particular application of current/pressure control
signals to the hydraulic valve of the control system
30   over a period of time; and

         FIG. 5 is a graphical representation of actual
and desired accelerations of a PTO shaft.

         FIG. 6 is a flowchart representative of one
embodiment of the functionality of step 90 of the
35   flowchart of FIG. 3A.

FIG. 7 is a flowchart representative of one embodiment of the functionality of step 98 of the flowchart of FIG. 3B.

FIG. 8 is a graphical representation of actual
5   and desired speeds of a PTO and engine speed of an agricultural vehicle during engagement of the PTO;

FIG. 9 is a flowchart representative of one embodiment of the functionality of step 94 of the flowchart of FIG. 3B; and
10   FIG. 10 is a flowchart representative of an additional operational steps that may be included in a point A in the operational sequence in FIG. 6.

Detailed Description Of The Invention
15   FIG. 1 depicts an embodiment of a power take-off (PTO) clutch control system 10 for an agricultural vehicle (such as a tractor schematically represented by the dashed line labeled 12) that includes the present invention. With the exception of the PTO clutch control
20   system 10, tractor 12 may be a conventional agricultural tractor of the type including an engine 14 having conventional accessories such as an alternator 16. Engine 14 is the power source for tractor and, in addition to providing power to the drive wheels (not
25   shown) of tractor 12, provides the power to apply rotational motion to a multi-plate hydraulically actuated PTO clutch 18. Depending upon whether PTO clutch 18 is engaged, power from engine 14 may in turn be transmitted to an output shaft 32. Output shaft 32
30   is shown directly coupled to a 1000 RPM PTO (high speed PTO) shaft 33 and also is shown coupled to a 540 RPM PTO (low speed PTO) shaft 35 by a reduction gear 37. In alternative embodiments, high speed PTO shaft 33 may be of another speed rating such as 750 RPM. While, in
35   alternate embodiments, high and low speed PTO shafts 33

and 35 may be provided at separate output terminals on tractor 12, preferably each PTO will be employed at a single output terminal (one PTO may be substituted for the other).

5   Control system 10 includes a controller 20 (including, e.g., a digital microprocessor such as the Intel TN83C51FA), a PTO on/off switch 22, an output clutch speed transducer 26, and a normally closed, solenoid operated, hydraulic, proportional clutch

10   control valve 28. Control system 10 also is coupled to alternator 16 and receives a signal therefrom representing the speed of engine 14.

        The engine speed is equal to or, depending upon gear reduction, a multiple or proportion of the

15   speed of an input shaft 19 to PTO clutch 18 that receives power from engine 14 and transmits power to the clutch. In alternate embodiments, a signal representative of the speed of input shaft 19 (that is directly representative of the speed of engine 14) may

20   be obtained by way of an input shaft transducer 24 coupled to shaft 19 instead of alternator 16. Consequently, for purposes of this document, reference may interchangeably be made to the engine and/or its speed or to the input shaft and/or its speed, with like

25   effect, and treating the speeds as being alike although they may differ proportionally.

        Transducers 24 and 26 may, by way of example and not of limitation, be variable reluctance sensors.

        Alternator 16 and transducer 26 are coupled to

30   digital inputs of controller 20 by, respectively, electrical conductors 21 and 29 and conditioning circuits 79 and 38, which may be integral to controller 20. (In alternative embodiments in which signals regarding input shaft 19 are provided by

35   transducer 24, an electrical conductor 25 along with

conditioning circuit 38 may be employed.) Conditioning circuits 79 and 38 filter radio and other undesirable frequencies of interference from the signals produced by alternator 16 and transducer 26 (or, in alternate

5   embodiments, transducer 24) and introduced in conductors 21 and 29 (or, in alternate embodiments, conductor 25). Additionally, conditioning circuits 79 and 38 typically place the signals produced by alternator 16 and transducer 26 (or transducer 24) within a 5 V range and

10   typically provide these signals with a generally square wave configuration which can be appropriately sampled by controller 20. Accordingly, the signals applied to controller 20 by alternator 16 (or transducer 24) and transducer 26 typically have a generally square wave

15   configuration with a frequency proportional to the rotational speed of input shaft 19 (or of engine 14) and output shaft 32, respectively.

        Switch 22 has associated therewith a conditioning circuit 40, which may be integral to

20   controller 20. Depending upon the application, circuit 40 may provide signal inversion and appropriate filtering to eliminate switch bounce. However, depending upon the type of controller 20 used, circuit 40 may be eliminated. The signal produced by switch 22

25   is applied to a digital input of controller 20 via electrical conductor.

        Hydraulic valve 28 is coupled to a digital output of controller 20 by an appropriate amplification and signal conditioning circuit 44, which may be

30   integral to controller 20, and electrical conductor 48. As will be discussed in greater detail below, controller 20 applies a signal, such as an analog or a pulse-width modulated (PWM) signal, to valve 28 via electrical conductor 48 and circuit 44. Due to the nature of the

35   solenoid that operates valve 28, amplification and

isolation circuit 44 is utilized to produce a control
signal having sufficient voltage and current to operate
valve 28. Additionally, due to inductive kickbacks
which may potentially be produced by the solenoids of
5   valve 28, isolation may be provided in circuit 44 to
protect controller 20. While controller 20 is typically
configured to apply an analog current signal to valve
28, in alternative embodiments an analog voltage signal,
a pulse-width modulated (PWM) current signal, or a PWM
10   voltage signal can be similarly employed and provided to
valve 28. In each case, the magnitude of the signal
provided (which, in the case of a PWM current or voltage
signal, is the time-average magnitude of the signal and
therefore depends upon the duty cycle or pulse width of
15   the signal) is proportional to the desired pressure from
valve 28.

          Turning to the operation of valve 28, valve 28
is a proportional hydraulic valve which applies
hydraulic fluid to PTO clutch 18 from the system
20   hydraulic fluid source 52 at a pressure which is related
to (e.g. proportional to) the time-averaged voltage
applied to the solenoid associated with valve 28. Thus,
the pressure of the fluid applied to PTO clutch 18 via
hydraulic conduit 36 by valve 28 may be controlled by
25   applying a variable current signal to valve 28. In
alternate embodiments, the pressure may be controlled by
applying a variable voltage signal, a PWM current
signal, or PWM voltage signal to valve 28. Where a PWM
signal is applied to the solenoid of valve 28 to control
30   the pressure of the hydraulic fluid applied to PTO
clutch 18, the pressure of the fluid is proportional to
the pulse width of the PWM signal produced by
controller 20.

          As discussed above, PTO clutch 18 is a multi-
35   plate hydraulic clutch. This type of clutch is capable

of transferring a torque from clutch input shaft 19 to output shaft 32, where the torque is generally proportional to the pressure of the hydraulic fluid applied to PTO clutch 18. Output shaft 32 is shown directly coupled to 1000 RPM PTO (high speed PTO) 33 and also is shown coupled to 540 RPM PTO (low speed PTO) 35 by reduction gear 37. In alternative embodiments, high speed PTO 33 may be of another speed rating, such as 750 RPM. Accordingly, the torque transferred between shafts 19 and 32 will be generally proportional to the magnitude of the analog current signal applied from controller 20 to the solenoid of valve 28. (In alternate embodiments where an analog voltage signal, a PWM current signal, or a PWM voltage signal is provided to valve 28, the torque transferred between shafts 19 and 32 also will be generally proportional to the magnitude of the applied signal, which in the case of a PWM signal is proportional to the duty cycle or pulse width of the signal.) While, in the ideal case, it may be convenient to have the torque transferred between shafts 19 and 32 exactly proportional to the magnitude of the current signal applied to valve 28, in mechanical systems such a relationship may be difficult to obtain. Accordingly, controller 20 is programmed to compensate for the inability to obtain such proportionality, and overall non-linearity in the electronics and mechanism of the control system 10.

Also shown in FIG. 1 is an implement 17 that may be attached to (typically, towed by) tractor 12. Implement 17 includes equipment (not shown) that is operated by way of power from tractor 12. The equipment may perform one or more actions upon a field, such as planting or tilling. Implement 17 is capable of receiving power from tractor 12 via an implement input shaft 51 coupled to high speed PTO 33 via a coupler 47.

When PTO clutch 18 is engaged and is transmitting power
from engine 14 to output shaft 32 and high speed PTO 33,
power is also then transmitted to implement input shaft
51. In addition to implement input shaft 51,
5   implement 17 also include an implement output shaft 85
that couples, and transmits power from, the implement
input shaft to the equipment. Implement input shaft 51
and implement output shaft 85 are coupled via an over-
running clutch 87. Over-running clutch 87 allows
10   implement output shaft 85 to continue to rotate freely
even when implement input shaft 51 is not rotating, and
allows the implement output shaft to rotate at a higher
angular velocity than the implement input shaft. If
locking pins and notches (not shown) of over-running
15   clutch 87 are not engaged, implement input shaft 51 must
rotate a portion of a rotation to engage the pins with
the notches before the over-running clutch will transmit
power from the input shaft to implement output shaft 85.
Implement input shaft 51 is coupled to high speed
20   PTO 33. In alternate embodiments, a similar implement
input shaft may be coupled to low speed PTO 35 by way of
a second coupler (not shown).
        Referring now to FIG. 2, controller 20 is
depicted as including a memory circuit 54 (which may
25   include RAM and ROM) and/or as being configured or
programmed to provide the operations of a speed sensing
circuit 56, a timing circuit 58, a switch status
monitoring circuit 60, a signal processing circuit 62,
and a valve control signal output circuit 64. The
30   direction and channels for data flow between circuits
54, 56, 57, 58, 60, 62 and 64 are shown in FIG. 2. The
ROM of memory circuit 54 stores those values required
for system 10 initialization and the constants required
for the operation of certain programs run by
35   controller 20. The RAM of memory 54 provides the

temporary digital storage required for controller 20 to execute the system program. While, at the present time, memory such as RAM and/or ROM is preferred, memory need not be limited to such types, and other memory types,

5 including for example, chemical, optical, bubble, and biological, can also be utilized as may be appropriate.

It will be appreciated by those skilled in the art, that, although reference has been made hereinabove to various circuits and memory and to operations

10 described and discussed with reference thereto, such referenced circuits and their operations, including operations as discussed and described hereinafter, may, in various embodiments, be considered to be encompassed within or associated with a programmed or programmable

15 processor or microprocessor and its associated memory and input and output circuitry. In such regard, and with particular regard to various embodiments of control system 10, actions associated herein with various circuit portions of controller 20 may thus be

20 effectively carried out or accomplished in accordance with the programming of a microprocessor or other control device or mechanism or by other devices or mechanisms so connected as to operate in a like or similar manner to perform the necessary actions.

25 Frequency interface circuit 57 and speed sensing circuit 56 receive signals from alternator 16 and transducer 26 that are applied to conductors 25 and 29, and convert the signals to digital values representative of the rotational speeds of engine 14 (or

30 input shaft 19) and output shaft 32, respectively. (In alternative embodiments, speed sensing circuit 56 may receive signals from transducer 24 that are applied to conductor 25, and convert those signals to digital values representative of the rotational speed of input

35 shaft 19, in place of or in addition to frequency

interface circuit 57, alternator 16 and conductor 21.)
Insofar as the output of alternator 16 is a square-wave,
frequency interface circuit 57 may operate as a timing
interface that measures the time between pairs of edges
5   of the square wave.

Timing circuit 58 includes counters which are
utilized by signal processing circuit 62 while executing
the programming represented by the flow charts of
FIGS. 3A and 3B.

10   Switch status monitoring circuit 60 converts
the signals applied by switch 22 to conductor 23 to
digital values representative of the status of these
switches.

Valve control signal output circuit 64
15   produces an analog signal, such as an analog current
signal, applied to the solenoid of valve 28 via
conductor 48 and isolation circuit 44, having an
appropriate magnitude.

As is briefly discussed below, the program
20   executed by controller 20 is preferably executed at
100 Hz (although, in alternate embodiments the program
could be executed at other frequencies). (In an
alternate embodiment in which valve 28 is provided with
a PWM current or voltage signal, valve control signal
25   output circuit 64 would produce a 400 Hz PWM current or
voltage signal having an appropriate pulse width.
Assuming the same program execution frequency of 100 Hz,
the pulse width of the signal from circuit 64 would be
updated every 10 milliseconds or every 4 cycles of the
30   PWM signal.)

FIGS. 3A and 3B depict a representative
operational sequence of a PTO engagement and operation
such as might occur with the system of the present
invention, and FIG. 4 illustrates the effects of such an
35   operational sequence. Basically, there are three

sequential modes of electrical signal modulation of the
PTO valve, designated as the FILL MODE, the MODULATION
MODE and the RAMP MODE, which are indicated along the
horizontal axis in Figure 4. The vertical axis in

5   FIG. 4 represents the PTO valve current in units of
amps, and the horizontal axis represents time.
Typically, the PTO module modulates the valve by varying
analog current to the coil. Superimposed on the control
current is a fixed frequency dither signal. FIG. 4 is a

10   representational figure whose purpose is to illustrate
certain features, and is therefore not necessarily to
scale.

        I_{INIT} shown in FIG. 4 is the current level at
which a PTO solenoid coil is cracking the PTO valve open

15   just enough for the PTO clutch to start carrying torque.
The value of this current level comes from PTO
calibration which may be predetermined or otherwise
established in various ways. The value of such current
is typically between 200 - 400 ma.

20   Time t_{s1} in FIG. 4 is the time at which the PTO
control current reaches I_{INIT}, typically around 500 ms.

        The FILL MODE may be considered to have three
identifiable stages: VALVE WAKE-UP, GENTLE INCREMENT,
and LOW ENERGY SHOCKS. FILL MODE begins at t_0 with PTO

25   speed at zero when PTO switch 22 is closed and ends when
PTO speed (output shaft movement) is detected, such as
at T_1. The time at which PTO speed is detected is the
start of the MODULATION MODE.

        The FILL MODE preferably starts with a VALVE

30   WAKE-UP stage. The waking up current is typically about
200 ma above I_{INIT}. The duration of such stage may be
made to depend upon how long the PTO has been in OFF
state, and may typically be set, as indicated below:

PTO off time	Wake-up duration
<= 500 msec	0
> 500 msec	10 msec
> 800 msec	20 msec
> 1200 msec	30 msec
> 2000 msec	40 msec
> 4000 msec	60 msec
> 6300 msec	70 msec

Utilization of a VALVE WAKE-UP stage speeds up the filling up of the PTO valve and conditions the valve to be ready to carry torque.

After valve wake-up, the current will preferably drop to about 40 ma below I_{INIT} and thereafter quickly enter the GENTLE INCREMENT stage. During such stage, the current keeps increasing, generally gently after, perhaps, a more pronounced initial increment, until either 1.5 seconds has passed or PTO speed is detected, with the current to the PTO valve typically increasing by approximately .03% of the maximum current every 10 ms. It has been found desirable to increment the current so that, by time T_{INIT}, the current will typically have reached I_{INIT}, and that, after approximately 1.5 seconds, the applied current will typically be about 40 ma above I_{INIT}. If no PTO shaft speed has been detected by such time, the FILL MODE will then enter the LOW ENERGY SHOCKS stage.

The desirability of utilizing a LOW ENERGY SHOCKS stage arises because some implements require the application of higher current to the valve in order to break the implement loose (e.g., frictions, heavy static loads, etc.), but lower current to ramp up speed. During the LOW ENERGY SHOCKS stage, low energy shocks, such as roughly 10 Hz pulses riding the base current increment, may be applied to more readily break loose

the implement and to effect movement of the output
shaft. The amplitudes of such pulses preferably starts
from about 10 ma and gradually increases to about 50 ma.

5   It has been found that, after approximately
3.6 seconds, the torque capacity should typically be
about enough to kill the engine. If no PTO shaft speed
is detected by that time, and the engine has not been
killed, the software will preferably stop the FILL MODE
and terminate the PTO operation. The operator will then
10   need to re-initialize the system, such as by turning the
PTO switch Off and then back On to restart the PTO.

       If, at any time during the FILL MODE, PTO
shaft speed is detected, the FILL MODE ends and the
MODULATION MODE starts.

15   The operation of controller 20, especially
with regard to the FILL MODE, will now be described in
greater detail with reference to FIGS. 3A and 3B
(FIGS. 3A and 3B represent the operational steps of the
program run by controller 20.) Upon system startup at
20   step 66, controller 20 reads the ROM of memory circuit
54 and initializes the counter in timing circuit 58.
Controller 20 also initializes those other variables and
constants which may be utilized in the programming of
controller 20 as it proceeds to and through step 68.

25   At step 70, controller 20 checks the digital
value representative of the status of PTO on/off switch
22, such as is available from switch status monitoring
circuit 60, and remains in a loop back to such step if
switch 22 is not detected as being closed. Once
30   switch 22 is detected to be closed, operation will then
advance to step 88 and proceed to execute the steps
required to begin (or continue) engagement of clutch 18.

       At step 88, by checking the value
representative of the rotational speed of output
35   shaft 32, controller 20 determines whether or not

shaft 32 is moving, and proceeds to step 90 if the
output shaft 32 is not moving or to step 91 if the
output shaft 32 is moving.

   If the output shaft 32 is not moving and
5   operation has proceeded to step 90, the system is in its
FILL MODE of operation and controller 20 sets a fill
current value, which is dependent, in part, upon the
particular time count.

   In general, at step 90 the fill current value
10   may be set in accordance with a predetermined
current/pressure control curve, such as has been
discussed generally hereinabove, but at specific times
during the LOW ENERGY SHOCKS stage the current value
will be increased so as to provide a current shock to
15   the clutch system. By way of example, at other than the
specific times for application of current shocks,
controller 20 may read the time associated with the
times since the PTO switch was closed, such as from a
timer counter of circuit 58, and set the current
20   magnitude value to a predetermined percentage if
switch 22 has been closed less than a given time. If
the time is greater than that given time, the current
magnitude value may be increased by 0.1% for each 10 ms
increment of time elapsed subsequent to switch 22 being
25   closed for that given time. (In an alternative
embodiment, the pulse width may be set to a
predetermined percentage (e.g., 20%) of the maximum
pulse width value if switch 22 has been closed for
300 ms or less. If the time is greater than 300 ms, the
30   pulse width value may be increased by 0.1% for each
10 ms increment of time elapsed subsequent to switch 22
being closed for 300 ms.)

   At the specific times at which current shocks
are to be applied, the current values are set to a
35   significantly higher value than would otherwise be the

case. FIG. 6 is a flowchart setting forth one
embodiment of a more detailed operational sequence of
step 90 of FIG. 3A, showing how the current shock
values, such as the increased magnitude of the current,
5   can be set to occur at times t_{S1}, t_{S2}, t_{S3}, and t_{SN}.
Although only a single shock is depicted in Fig. 4 at
such times, it should be appreciated that application of
a series of shocks commencing at such times is also
possible and preferable.

10   When no movement of the output shaft 32 has
been detected at step 88 and the engagement operation
has progressed to step 90, then with particular
reference to FIG. 6, at step 90A controller 20 checks
whether the then-current time is time t_{S1}, the time at
15   which a first current shock is to be applied if the
output shaft 32 has not commenced movement by that time.
If the time t is t_{S1}, controller 20 proceeds to step 90B
where it sets the current value to be used in applying
the current shock at time t_{S1} before proceeding through
20   point C of FIG. 6 to step 104 of FIG. 3A.

         If, at step 90A, the then-current time is not
equal to t_{S1}, controller 20 proceeds to step 90C where it
next checks whether t is equal to t_{S2}, the time at which
a second current shock is to be applied if the output
25   shaft 32 has not commenced movement by that time.   If
the time t is t_{S2}, controller 20 proceeds to step 90D
where it sets the current value to be used in applying
the current shock at time t_{S2} before proceeding through
point C of FIG. 6 to step 104 of FIG. 3A.

30   If, at step 90C, the then-current time is not
equal to t_{S2}, controller 20 proceeds to step 90E where it
next checks whether t is equal to t_{S3}, the time at which
a third current shock is to be applied if the output
shaft 32 has not commenced movement by that time.   If
35   the time t is t_{S3}, controller 20 proceeds to step 90F

where it sets the current value to be used in applying
the current shock at time t_{S3} before proceeding through
point C of FIG. 6 to step 104 of FIG. 3A.

     If, at step 90E, the then-current time is not
5   equal to t_{S3}, controller 20 can proceed to other steps
such as step 90G, if the system is designed to provide
additional current shocks at other times, or, if no
additional current shocks are to be applied with a
particular system, to step 90I. At step 90G,
10   controller 20 checks whether t is equal to t_{SN}, the time
at which an Nth current shock is to be applied if the
output shaft 32 has not commenced movement by that time.
If the time t is t_{SN}, controller 20 proceeds to step 90H
where it sets the current value to be used in applying
15   the current shock at time t_{SN} before proceeding through
point C of FIG. 6 to step 104 of FIG. 3A. If t is not
equal to t_{SN} at step 90G (or to a value of t at any of
steps 90A, 90C, or 90E, if the system is designed to
apply fewer than 2, 3, or N shocks, respectively),
20   controller 20 proceeds to step 90I where it sets the
fill current value for time t in a manner such as has
been previously explained hereinabove with reference to
step 90 of FIG. 3A before proceeding through point C of
FIG. 6 to step 104 of FIG. 3A.

25   FIG. 10 is another flowchart setting forth an
optional feature that may be included within the
operational sequence of FIG. 6, including additional
steps at point A of FIG. 6, showing how a current shock
value can be triggered by detection of engine droop
30   prior to detection of movement of output shaft 32. As
shown in FIG. 10, upon reaching step 90 (in FIG. 3A),
and before proceeding to step 90A, controller 20 may
first determine whether a DROOP flag has been set. If
such a flag has been previously set, the controller may

proceed, for example, either to point B of FIG. 6 or to step 90A of FIG. 6, depending upon particular systems.

If, however, DROOP flag has not been previously set, controller 20 proceeds to step 90K, where it checks to see if any engine droop (or a degree of engine droop) is detected. If not, controller 20 proceeds to step 90A on FIG. 6; if so, it proceeds to step 90L.

At step 90L, controller 20 sets the DROOP flag before proceeding to step 90M, where controller 20 sets a current shock valve to be applied, at $t=T_{DROOP}$, before proceeding to and through point C of FIG. 6 to step 104 of FIG. 3A.

Once the current value for time t has been set at step 90, such as at steps 90B, 90D, 90F, 90H, or 90I of FIG. 6 or step 90M of FIG. 10, operation then proceeds to step 104 (FIG. 3A), which step will be further addressed at a later point hereinafter.

From the foregoing discussion and description, it should be understood that a purpose of steps 88 and 90 is to effect smooth engagement of PTO clutch 18. A certain volume of hydraulic fluid must be provided to PTO clutch 18 before the clutch plates of PTO clutch 18 travel through the distance required to engage the clutch plates. During a clutch filling process, it is undesirable to apply hydraulic fluid to the clutch at a fixed or undesirably high pressure since the clutch will abruptly apply torque from input shaft 19 to output shaft 32. Such an abrupt application of torque can potentially cause damage to output shaft 32 or an associated implement connected to the PTO output shaft. By initiating the filling of clutch 18 with a pressure equivalent to the pre-stress force applied by the clutch springs, and by applying current to the valve to effect a controlled filling of clutch 18, the clutch plates can

be made to move relatively slowly toward engagement, and
the pressure can be controllably increased gradually
until engagement. This process prevents the abrupt
transfer of torque from input shaft 19 to output
5   shaft 32.

As is depicted in a somewhat idealized form in
FIG. 4, following valve wake-up at time t_0, the
current/pressure applied over time from T_s starts at a
lower level and increases in accordance with the current
10   fill values established at step 90 until time T1, when
the first motion of the output shaft 32 occurs and is
detected at step 88. During the period between t_0 and
T1, at times t_{s1}, t_{s2}, and t_{s3}, current shocks are shown as
having been applied, consistent with current values as
15   set at steps 90B, 90D, and 90E. As shown in FIG. 4,
application of the current shocks need not occur at
equally spaced intervals from one another, but can occur
at times selected for and matched to particular systems.
As has previously been noted, during such time period
20   from t_0 to T1, following initial application of current
of a given magnitude for a short duration, it has been
found to be advantageous to gradually increment the
current, such as by approximately .03% of the maximum
current every 10 ms, until motion of the output shaft 32
25   is detected. As has previously been explained, the
current shocks provide a higher magnitude of current for
brief durations at the times of their application.

In alternative embodiments employing PWM
signals, the pulse width of the PWM signal may be
30   initiated at a certain duty cycle (e.g., 20%) at time t_0
and increased in gradual steps until output shaft 32
begins moving as determined at step 88. At the times
when a current shock is to be applied, the pulse width
may be expanded to achieve the short duration pressure
35   shock desired at the PTO clutch 18.

Referring now again to FIG. 3A, as has previously been discussed, once the fill current has been set, controller 20 proceeds from step 90 of FIG. 3A to step 104. At step 104, controller 20 checks if the

5 timer has timed out. If so, controller 20 proceeds to step 107 and terminates the PTO operation; if not, it proceeds directly to step 106.

At step 106, controller 20 operates to send the established current value to PTO clutch valve 28

10 before proceeding to step 109, where it updates the timer before proceeding to step 110. At step 110, controller 20 checks to see if the PTO switch is still closed. If not, controller 20 proceeds to step 107, where the PTO operation is terminated. If the switch is

15 still closed, however, controller 20 proceeds to step 108, which identifies a return to step 88 and commencement of another loop of the engagement operation. (At step 106, for embodiments that use PWM techniques, controller 20 may effect application of a

20 pulse width modulated signal to valve 28 via conductor 48 at a frequency of 400 Hz with a pulse width corresponding to the current pulse width value as set in that particular loop through the operation sequence.)

It will be appreciated that various checks and

25 actions may be associated with RETURN 108 for effecting a conclusion of the operational sequence and cessation of further looping through the sequence, depending upon the system.

It should be understood that the foregoing

30 discussion has now described the loop operation from step 88 through RETURN step 108 and back to step 88, which looping operation occurs during the FILL MODE. The controller 20 causes the timer counter to be updated by a specified amount upon each passage through

35 step 109, which amount is related to the time it takes

to cycle through the operational loop. (For the
programming represented by the flow charts of FIGS. 3A
and 3B, running at a rate of approximately 100 Hz, one
cycle is approximately 10 ms. Accordingly, for one
5   cycle, the counter is updated by a count value
associated with 10 ms.)

Referring again to FIG. 3A, upon a looping
pass through step 88, if shaft 32 is detected to be
(already) moving, FILL MODE ceases and system operation
10 enters (or continues) with either the MODULATION MODE or
RAMP MODE of operation as controller 20 proceeds to
step 91 instead of to step 90.

At step 91, if the movement detected at
step 88 is the first movement of the output shaft,
15 MODULATION MODE commences and controller 20 proceeds to
step 93 where it saves the time of such detected
movement as TIMER1, resets and starts a timer for
TIMER2, and sets a 1ST TIME flag before proceeding to
step 76 of FIG. 3B.

20 If the detected movement at step 91 is a
continuing movement of the output shaft instead of the
first detected movement, controller 20 proceeds directly
to step 76.

As is depicted on FIG. 4, MODULATION MODE
25 directly follows the FILL MODE and is initiated when PTO
speed (output shaft movement) is first detected. After
detection at T_1 of PTO shaft speed, controller 20
modifies the analog command signal to the valve based on
acceleration of the PTO clutch until PTO CLUTCH LOCK-UP
30 occurs (i.e., when PTO clutch slip meets the criteria
for a locked clutch condition) at T_L.

In general, during the period between PTO
speed detection and clutch lock-up, the analog command
signal is typically adjusted depending upon the
35 relationship between the calculated acceleration of the

PTO clutch compared to the target acceleration value. Controller 20 monitors engine rpm and assumes it will be constant for the next 2 seconds. From engine speed, the controller typically calculates the PTO acceleration

5 required to achieve PTO clutch lock-up within approximately 1.8 seconds. If the acceleration is lower than the target acceleration value, the control current will be increased accordingly unless the engine rpm has been loaded too low. If the acceleration is higher than

10 the target acceleration value, the control current will be decreased accordingly in the early stage of modulation. Typically, if modulation has been in process for over 1 second, or the PTO has been turned on for over 4 seconds, or the clutch slippage is less than

15 50%, the control current will not be decreased even if the acceleration is higher than the target acceleration value, although these features may be altered depending upon particular systems and users.

If output shaft movement occurs without

20 appreciable engine droop or the PTO shaft speeds up fairly quickly and without appreciable engine droop, the controller may optionally be programmed to recognize such conditions as being indicative of a no load or very light load condition, which could also initially signify

25 possible use of an over-running clutch. It has been found desirable to employ an even more gentle current modulation in such instances to accommodate the possibility that an over-running clutch is associated with the output shaft.

30 With the foregoing in mind, when operation proceeds to step 76 of FIG. 3B, controller 20 obtains the digital values representative of the rotational speeds of input shaft 19 (or engine 14) and output shaft 32, such as provided to signal processing

35 circuit 62 from circuits 56 and 57, and proceeds to

step 78, where it then compares the speeds of shaft 19 (or engine 14) and shaft 32, and, depending upon such comparison, proceeds either to step 80 or step 82.

If the shaft speeds are the same (or are within some degree of tolerance of the speeds or proportions thereof), signifying that PTO clutch lock-up has occurred, as will be further discussed hereinafter, MODULATION MODE terminates, RAMP MODE commences, and operation proceeds to step 80.

However, if, at step 78, the shaft speeds are not the same (or are not within some degree of tolerance of the speeds or proportions thereof), which is the expected situation when output shaft movement is first detected and MODULATION MODE commences, operation proceeds instead to step 82, where controller 20 checks to see whether or not the STEADY STATE flag has been set, (signifying that PTO clutch lock-up had previously occurred). During MODULATION MODE, the STEADY STATE flag will not as yet have been set and controller 20 will therefore proceed to step 94.

At step 94, controller 20 then sets a desired acceleration, which acceleration may, in some instances and with certain embodiments, be calculated once, upon a first pass through step 94 during a PTO engagement operation and thereafter relied upon in subsequent passes through step 94 during such engagement operation, and in other instances and with other embodiments, be recalculated in subsequent passes through step 94 in an engagement operation. By way of example, the desired acceleration, whether calculated once or multiple times, may be calculated such as by dividing the speed of the input shaft 19 at the time of calculation by 2 seconds.

In general, the first pass through step 94 is the start of the process for controlling clutch 18 to accelerate output shaft 32 relative to input shaft 19

until the speed of output shaft 32 reaches its steady state speed (no clutch 18 slip) which equals or is proportional to the speed of input shaft 19. The desired acceleration of output shaft 32 at step 94 is

5   preferably calculated based upon approximately 1.8-2.0 seconds, which has been selected, based upon experimentation, to provide optimum acceleration of output shaft 32. However, depending upon the system configuration, such time period may be varied according

10 to the particular tractor and PTO application. The calculated acceleration serves as a reference for accelerating output shaft 32 relative to input shaft 19 at step 96.

As is apparent from FIGS. 3A and 3B and as

15 will be readily understood by those skilled in the art, and as is discussed and described in U.S. Patent No. 6,267,189, the PTO clutch control system can repeatedly set a new, updated desired acceleration as it passes through step 94. As is evident from a study of

20 FIGS. 3A and 3B, so long as the speeds of input shaft 19 and output shaft 32 remain different (as determined in step 78), the control system program repeatedly cycles through step 94. In embodiments in which the desired acceleration is recalculated each time the PTO clutch

25 control system cycles through step 94 (instead of only the first time), the desired acceleration may be repeatedly calculated by dividing the current speed of shaft 19, or another quantity related to engine speed, by the desired time of engagement, which is preferably

30 1.8-2.0 seconds in the embodiments described herein. Although in alternate embodiments the frequency of recalculation may vary (or the recalculation may occur at a frequency less than the frequency at which the control system program cycles through step 94), it has

35 been found desirable to have the desired acceleration

recalculated at the same frequency as the control system
program cycles through step 94, which (as stated above)
is approximately 10 ms. Such recalculation occurs with
sufficient rapidity that the desired acceleration is
5   effectively continuously recalculated to reflect changes
in the speed of input shaft 19 (that is, changes in
engine speed).

Referring to FIG. 8, examples of the desired
and actual speeds for output shaft 32 (i.e., PTO speed),
10   and engine speed (i.e., the speed of input shaft 19), as
measured or determined by the PTO clutch control system
of an embodiment that recalculates the current desired
acceleration during the engagement operation, are
plotted against time. Four desired speed curves are
15   shown. The four speed curves are determined based upon
the engine speed (or speed of input shaft 19) as
measured at four times, t_a, t_b, t_c, and t_d and are labeled
as, and referred to below as, respectively, the "desired
PTO speed #a", "desired PTO speed #b", "desired PTO
20   speed #c" and "desired PTO speed #d" curves. For
convenience, only four desired speed curves are shown in
FIG. 8. As discussed above, the desired accelerations
in the present embodiment are actually recalculated
approximately every 10 ms (effectively continuously),
25   and so FIG. 8 is meant to be a symbolic description of
the actual operation of the PTO clutch control system,
in which there are many more than four desired speed
curves. Also, it is for generality that the four desired
speed curves are shown as being calculated at four times
30   (times t_a - t_d) that are not equidistant from one
another. Although alternative embodiments may vary, it
has been found desirable to have the desired
accelerations (in contrast to FIG. 8) recalculated at a
constant frequency as the PTO clutch control system
35   repeatedly cycles through step 94.

As is depicted in FIG. 8, output shaft 32 begins to rotate at time t_a, and the speed of the output shaft equals the speed of input shaft 19 (or the engine speed) at time t_e (lock-up), which corresponds to T_L of FIG. 4. Also, as shown, the speed of input shaft 19 (and of engine 14) does not remain constant as power begins to be transferred to output shaft 32, but, instead, decreases or droops. Consequently if the actual speed of output shaft 32 were to increase in accordance with the desired PTO speed #a curve, which is determined based upon the initial engine speed at time t_a, the shaft would attain the speed of input shaft 19 (i.e., the engine speed) in a time significantly shorter than the desired time of engagement (the time interval between times t_a and t_e, i.e., 2 seconds). Instead of attaining the speed of input shaft 19 at time t_e, the shaft would attain the speed of the input shaft at the time at which, as shown in FIG. 8, the desired PTO speed #a curve crosses the engine speed curve.

The embodiments that repeatedly recalculate the desired acceleration avoid this excessive engagement rate by adjusting the desired speed curve as engine speed decreases. As shown in FIG. 8, at times t_b, t_c, and t_d the desired acceleration is recalculated (at step 94 of the control system program) and the desired speed curve changes, respectively, to the desired PTO speed #b, desired PTO speed #c, and desired PTO speed #d curves. As described below, with such embodiments the actual acceleration of output shaft 32 is adjusted as the desired speed curve changes (more specifically, the actual acceleration is adjusted based upon the difference between the actual and desired accelerations). Insofar as the actual acceleration of output shaft 32 is adjusted to reflect the new desired speed curves, the output shaft speed increases at a rate

such that it will approach the speed of input shaft 19 (i.e., the engine speed) at approximately t_e (i.e., within the desired time of engagement, i.e., 2 seconds), as shown in FIG. 8, and not substantially before t_e.

5   It will be appreciated that it is also advantageous to be able to utilize different acceleration control curves depending upon the type of load that the PTO is driving. FIG. 9 is a flowchart depicting in greater detail one manner in which this can be accomplished at step 94 in the engagement operation process.

    During MODULATION MODE, controller 20, upon reaching step 94, will, at step 94A, check to determine if any load flags have already been set. If so, controller 20 proceeds to step 94K; if not, it will proceed instead to step 94B.

    At step 94B, controller 20 checks whether the saved TIMER1 value is less than t_{s1}, the time at which the first current shock was to be applied. If so, the output shaft 32 commenced movement before the scheduled time for the first current shock, as a consequence of which the load is therefore classified as or considered to be a light load, and controller 20 proceeds to step 94C, where it sets a LIGHT LOAD flag before proceeding to step 94K.

    If, at step 94B, the saved TIMER1 value is not less than t_{s1}, controller 20 proceeds to step 94D, where it checks whether the TIMER1 value is less than t_{s2}, the time at which the second current shock was to be applied. If so, the output shaft 32 commenced movement after the scheduled time for the first current shock but before the scheduled time for the second current shock, as a consequence of which the load is therefore classified as or considered to be a medium load, and

controller 20 proceeds to step 94E, where it sets a
MEDIUM LOAD flag before proceeding to step 94K.

If, at step 94D, the saved TIMER1 value is not
less than t_{s2}, controller 20 proceeds to step 94F, where

5   it checks whether the TIMER1 value is less than t_{s3}, the
time at which the third current shock was to be applied.
If so, the output shaft 32 commenced movement after the
scheduled time for the second current shock but before
the scheduled time for the third current shock, as a

10 consequence of which the load is therefore classified as
or considered to be a heavy load, and controller 20
proceeds to step 94G, where it sets a HEAVY LOAD flag
before proceeding to step 94K.

If, at step 94F, the TIMER1 value is not less

15 than t_{s3}, controller 20 can proceed to other steps such
as step 94H, if the system is designed to categorize
additional load types, or, if no additional load types
are to be categorized with a particular system, to
step 94K. At step 94H, controller 20 checks whether the

20 TIMER1 value is less than t_{sN}, the time at which the Nth
current shock was applied. If so, the output shaft 32
commenced movement after the scheduled time for the
(N-1)th current shock but before the scheduled time for
the Nth current shock, as a consequence of which the

25 load is therefore classified as or considered to be, for
example, a very heavy load, and controller 20 proceeds
to step 94I, where it sets a VERY HEABY LOAD flag before
proceeding to step 94K.

If, at step 94H, the TIMER1 value is not less

30 than t_{sN}, the load is classified as or considered to be,
for example, an extreme load, and controller 20 proceeds
to step 94J, where its sets an EXTREME LOAD flag before
proceeding to step 94K.

Upon reaching step 94K, controller 20 then

35 determines the desired acceleration for the load type

being driven, such as in the manners previously
described relative to step 94 of FIG. 3B, before
proceeding to step 96 of FIG. 3B.

At step 96, controller 20 checks to determine
whether the output shaft acceleration is less than the
desired acceleration that was set at step 94. In order
to perform such check, the then-current shaft
acceleration must be first calculated, such as based
upon the speed of shaft 32 available from circuit 56 at
that time and the speed of shaft 32 as monitored during
the previous loop and stored in memory, such as at
step 76. If an operational loop through step 96 is
executed every 10 ms, the shaft acceleration is then the
change in shaft speed between program loops divided by
10 ms.

If, at step 96, the actual calculated
acceleration of shaft 32 is less than the desired shaft
acceleration as set at step 94, operation proceeds to
step 98. On the other hand, if the actual calculated
acceleration of shaft 32 is greater than or equal to the
desired shaft acceleration as set at step 94, operation
proceeds to step 99, instead, where the current is
limited, before proceeding to step 100.

If the actual acceleration of output shaft 32
is less than the desired shaft acceleration and
operation has proceeded to step 98, controller 20 then
operates to increase the magnitude of the current. The
particular manner in which current magnitude changes may
vary for different control system embodiments.

At step 98, a first control system embodiment
(here referred to as the "unmodified PTO clutch control
system embodiment") may, whenever the desired
acceleration exceeds the actual acceleration, increase
the current magnitude by 0.1%.

An alternate second control system embodiment
(here referred to as the "modified PTO clutch control
system embodiment") may employ a proportional (more
accurately, pseudo-proportional) adjustment algorithm to
5   determine the increase in current. In accordance with
such an algorithm, the control system may operate (a) if
the actual acceleration of the PTO is determined to be
less than the desired acceleration but greater than two-
thirds of the desired acceleration, to apply current so
10   as to increase the torque transmitted by the PTO clutch
at a slow rate; (b) if the actual acceleration of the
PTO is determined to be less than two-thirds of the
desired acceleration but greater than one-third of the
desired acceleration, to apply current so as to increase
15   the torque transmitted at a medium rate; and (c) if the
actual acceleration of the PTO is determined to be less
than one-third of the desired acceleration, to apply
current so as to increase the torque transmitted at a
fast rate.
20   A third control system embodiment (here
referred to as the "modified proportional adjustment
algorithm PTO clutch control system embodiment") has
also been found to be practical and useful. FIG. 7 is a
flowchart depicting the operational flow of one
25   embodiment of the functionality of step 98 of the
flowchart of FIG. 3B for a modified proportional
adjustment algorithm PTO clutch control system
embodiment. At step 98a, controller 20 determines if
the actual acceleration is between the desired
30   acceleration and two-thirds of the desired acceleration.
If so, the program increases the current magnitude at a
slow rate in step 98d before exiting step 98. If not,
controller 20 proceeds to step 98b, at which it
determines whether the actual acceleration is between
35   two-thirds of the desired acceleration and one-third of

the desired acceleration. If so, controller 20 increases the current magnitude at a medium rate in step 98e. If not, controller 20 proceeds to step 98c, at which it determines whether the actual acceleration

5 is between one-third of the desired acceleration and one-sixth of the desired acceleration. If so, controller 20 increases the current magnitude at a fast rate in step 98f. If not, the actual acceleration is between zero and one-sixth of the desired acceleration,

10 and controller 20 proceeds to step 98g at which it increases the current magnitude at a slow rate. (It should be noted that the program may be designed to treat actual accelerations that exactly equal two-thirds, one-third, or one-sixth of the desired

15 acceleration as if the actual accelerations were above or below these levels.)

A significant characteristic of the modified proportional adjustment algorithm is that the modified proportional adjustment algorithm (a) determines whether

20 the actual acceleration is below a minimum threshold proportion of the desired acceleration, and (b) increases the current magnitude at a slow rate if the actual acceleration is below the minimum threshold proportion even though the actual acceleration is

25 significantly less than the desired acceleration. That is, in such an embodiment, the modified proportional adjustment algorithm determines in step 98c whether the actual acceleration is below one-sixth of the desired acceleration and, if so, increases the current magnitude

30 at a slow rate in step 98g.

This feature of the modified proportional adjustment algorithm alleviates problems such as are described in U.S. Patent No. 6,267,189 that are associated with possible spurious rotations of output

35 shaft 32 due to premature delivery of torque by PTO

clutch 18 (before the clutch is fully engaged) that may
occur, for example, before over-running clutch 87 is
locked. This is because, typically, once PTO clutch 18
is engaged and output shaft 32 is being accelerated, the
5   output shaft would not have an actual acceleration less
than one-sixth of the desired acceleration. Further,
typically, PTO clutch 18 is not capable of delivering
sufficient torque when the clutch is not fully engaged
so as to cause output shaft 32 to accelerate at a rate
10   greater than one-sixth of any of the desired
accelerations that may be calculated by control
system 10.   Therefore, the modified proportional
adjustment algorithm fulfills the two goals of (a)
causing the current magnitude to increase at a fast rate
15   when the actual acceleration of output shaft 32 is
significantly less than the desired acceleration and yet
(b) not causing the current magnitude to increase at a
fast rate when PTO clutch 18 is still not fully engaged.
        While, in such an embodiment, the ratios of
20   actual acceleration to desired acceleration that
determine the current magnitude increase rates are
preferably set at two-thirds, one-third, and one-sixth,
in alternate embodiments the ratios may be set at
different levels.   Indeed, different PTO clutch control
25   systems may have a variety of different proportional
adjustment algorithms that distinguish among more (or
less) than four ranges (of ratios of actual acceleration
to desired acceleration) and in which the control
systems provide finer (or less fine) gradations of
30   increases in the current magnitude.   (Fully proportional
control may also be appropriate in certain embodiments.)
Also, the exact values for the "slow", "medium", and
"fast" rates of current increase may vary depending upon
the embodiment, although the "fast" rate of increase
35   will typically be the fastest rate at which the

mechanical clutch can predictably increase torque in
response to commands from the control system to increase
pressure. It should be noted that, while such an
embodiment of the invention combines both the
5 functionality of the modified proportional adjustment
algorithm and the above-described repeated (continuous)
recalculation of the desired acceleration (and
modification of the desired speed curve), the modified
proportional adjustment algorithm of step 98 may be
10 employed even when the desired acceleration is only
calculated once.

Although the foregoing discussion of steps 96
and 98 has focused on embodiments that make use of
increases in current magnitude in engagement operations,
15 embodiments that make use of increases in pulse width
may also be employed. With such embodiments, if, at
step 96, the actual acceleration of output shaft 32 is
determined to be greater than or equal to the desired
acceleration, the controller 20 proceeds to step 100,
20 leaving the pulse width value unchanged. If, at
step 96, the actual acceleration of output shaft 32 is
determined to be less than the desired acceleration, the
controller 20 proceeds instead to step 98, at which it
operates to increase the current pulse width by 0.1%.
25 In certain of such systems, it may be
desirable to reduce the pulse width value when the
actual acceleration of output shaft 32 is greater than
the desired acceleration. However, this type of control
may cause hunting, and thus an acceleration of shaft 32
30 which is not smooth. Accordingly, in the presently
preferred embodiments that utilize pulse width
modulation techniques, it is considered preferable to
leave the pulse width value unchanged when the actual
acceleration of shaft 32 exceeds the desired
35 acceleration. With such embodiments, a pulse width

increase of 0.1% for each 10 ms interval (i.e., for each pass through step 98) has been found to be advantageous and preferable.

Any of these control system embodiments (or
5 the programming contained therein) may be advantageously employed in conjunction with the control system described above in which the desired accelerations are repeatedly recalculated (i.e., such that the desired speed curve changes with engine speed).

10 Regardless of the particular embodiment, when the engagement operation reaches step 100 from either step 98 or step 99, controller 20 checks whether the increased current value, as set at steps 98, 99, or 102, exceeds the maximum allowable current value. If so,
15 controller 20 proceeds to step 101 and resets the current value to the maximum allowable value before proceeding through point A of FIGS. 3B and 3A to step 104 of FIG. 3A; if not controller 20 proceeds directly through point A of FIGS. 3B and 3A to step 104
20 of FIG. 3A.

Operation then proceeds in the manner previously described commencing at step 104 and continues in a MODULATION MODE operational loop until, at step 78 of FIG. 3B, the speeds are detected as being
25 the same. At that time, MODULATION MODE ceases and RAMP MODE commences.

Operation then proceeds from step 78 to step 80, instead of to step 82, and at step 80 controller 20 then resets the timer count and also sets
30 a STEADY STATE flag before proceeding to step 102. At step 102 controller 20 determines a current value to be applied, which, during RAMP MODE, may include incremental increases to the current value, such as by increasing the current magnitude by 1.00% (or, in

alternative embodiments, increasing the pulse width value by 1.00%), before proceeding to step 100.

Upon completion of step 102, controller 20 proceeds to step 100, and operation continues therethrough and thereafter as previously described, with continuing operational looping through steps 80 and 102 of the RAMP MODE loop.

After the maximum current value is reached (at T_{max}) in continuing passes through step 102, RAMP MODE is completed, and steps 100 and 101 act to limit the current value to the maximum current valve.

If, in operational passes after the STEADY STATE flag has been set at step 80, speeds are subsequently found to (again) be different at step 78, controller 20 proceeds to step 82, where it checks to see if the STEADY STATE flag is set. Since the flag has previously been set, controller 20 proceeds to step 83.

At step 83, controller 20 determines whether or not the speed difference between shaft 19 (or engine 14) and shaft 32 is greater than some allowable deviation value, such as fifteen percent (15%). If the speed difference is greater than fifteen percent (15%), operation proceeds to step 85, which is indicative of a fault condition and results in termination of PTO operation. If the speed difference is less than 15%, controller 20 proceeds instead to step 102, from which point the operation will proceed as previously described. Typically, if the STEADY STATE flag has previously been set and step 102 is reached from step 83, the determined current value will be set at or near to the maximum allowable current value.

Referring now to FIGS. 4 and 5 relative to the foregoing discussion, it should be observed that PTO clutch lockup occurs at time T_L when the speeds of input shaft 19 (or engine 14) and output shaft 32 become equal

or proportional, as detected at step 78 of FIG. 3B. Following such occurrence, so long as the speeds remain the same, operation sequence controller 20 repeatedly proceeds through steps 102 and 100, increasing the

5   current value with each pass through step 102, until the current value exceeds the maximum allowable current. At that point, and in subsequent passes through step 100, the current value is reset to the maximum allowable current value at step 101. Such actions cause the

10 current value to be ramped up over time to produce a clutch pressure in PTO clutch 18 associated with the maximum allowable torque to be transmitted between input shaft 19 and output shaft 32. If the current value ever becomes greater than the maximum allowable current

15 value, the current value is reset to the maximum allowable current value at step 101.

        For embodiments that utilize PWM techniques, following lockup at time T_L controller 20 proceeds through steps 100 and 102 to ramp up the pulse width

20 value to produce a clutch pressure in clutch 18 associated with the maximum torque to be transmitted between shafts 32 and 19. In step 100, the current pulse width value is compared with the maximum pulse width value. If the current pulse width value set at

25 steps 98, 99, or 102 is greater than the maximum pulse width value, controller 20 resets the pulse width value to the maximum pulse width value at step 101.

        It should be recalled from discussions hereinabove that differing time limits may be

30 established or utilized for different modes of the operation and that the timer is updated at step 109 of FIG. 3A as the looping operations proceed, as a consequence of which detection of a timing out of the timer at step 104 by the controller 20 may occur under

35 several different circumstances.

            In such regard, it should be recalled that one
manner of reaching step 104 is through on operational
loop including step 90. At step 90 the fill current
value is set when output shaft 32 is detected as not
5   moving at step 88. If, after operational looping during
FILL MODE for a certain time, the output shaft 32 has
not yet begun moving, controller 20 thus operates at
step 104 to terminate the PTO operation.
            Another manner in which step 104 can be
10   reached is through an operational loop including
steps 94, 96, and 98 or 99. If, after commencement of
MODULATION MODE, the speeds of the input shaft 19 and
the output shaft are not found to be the same at step 78
within a given time, lockup of the clutch has not
15   occurred within that time, and controller 20 again
operates at step 104 to terminate the PTO operation.
            A further manner in which step 104 can be
reached is through an operational loop including
step 102. During RAMP MODE, so long as the speeds of
20   the input and output shafts are the same, the timer is
reset upon each passage through step 80. If the speeds
differ at some point, however, operation will proceed
through step 82 to step 83, instead of to step 80, and
the timer will not be reset at step 80 in that loop. In
25   continuing passes through a loop that includes step 83
instead of step 80, the timer will be repeatedly updated
at step 109 (FIG. 3A) until either (a) the speeds are
again found to be the same at step 78, and the timer is
reset at step 80, or (b) the time limit for again
30   achieving the same speeds is reached at step 104 (with
such condition typically being indicative of undesirable
slippage in the PTO clutch 18), resulting in termination
of the PTO operation at step 107, or (c) detection of a
fault condition at step 83, resulting in termination of
35   the PTO operation at step 85.

In addition to the various checks performed
and conditions tested, as discussed and described in the
foregoing, additional checks and tests may be desirable
with various systems, including, by way of example,
5   periodic tests of engine speed and other operational
factors or considerations, and the outcomes of such
tests may be utilized in determining the course of
operations without departing from the spirit and scope
of the present invention.

10   Although various features of the control
system are described and illustrated in the drawings,
the present invention is not necessarily limited to
these features and may encompass other features
disclosed both individually and in various combinations.

15   For example, developments in PTO clutches may make
electric clutches cost effective for PTO applications.
Accordingly, hydraulic clutch 18 and control valve 28
may potentially be replaced with an associated electric
clutch and electric clutch control circuit.

20   It will be understood that changes in the
details, materials, steps, and arrangements of parts
which have been described and illustrated to explain the
nature of the invention will occur to and may be made by
those skilled in the art upon a reading of this

25   disclosure within the principles and scope of the
invention. The foregoing description illustrates the
preferred embodiment of the invention; however,
concepts, as based upon the description, may be employed
in other embodiments without departing from the scope of

30   the invention. Accordingly, the following claims are
intended to protect the invention broadly as well as in
the specific form shown.